Ka-to-L-band frequency down-conversion using a micro-photonic IIIV-on-silicon mode-locked laser and Mach-Zehnder modulator

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Being an integral part of communication systems, frequency conversion based on integrated microwave photonic technology surpasses its electronic counterpart in terms of weight, bandwidth and size. In this work we present a IIIV/Si Photonic Integrated Circuit-based down-conversion scheme that successfully converts 5 Ka-band channels with a 500 MHz bandwidth to L-band. The operation principle is based on the modulation of short optical pulses from a mode-locked laser (MLL) by the incoming RF signal. As shown in Fig. 1, an optical pulse train is fed into a Mach-Zehnder Modulator (MZM), which functions as a frequency mixer [1]. The two arms of the MZM are separately driven by the incoming RF signal and a tunable local oscillator (LO). When the two modulated optical signals are beating on a photodetector, various IF signals will be generated, by which the Ka band RF signal is effectively down-converted to L band. Flexible channel selection can be achieved by tuning the LO frequency while keeping the MLL repetition rate constant. In the presented case, the MLL with a fundamental repetition rate of 2.658 GHz is harmonically mode-locked at a repetition rate of 15.584 GHz, while the LO is varied between 2.918 and 4.918 GHz to down-convert five RF channels varying from 27.75 GHz to 29.75 GHz.

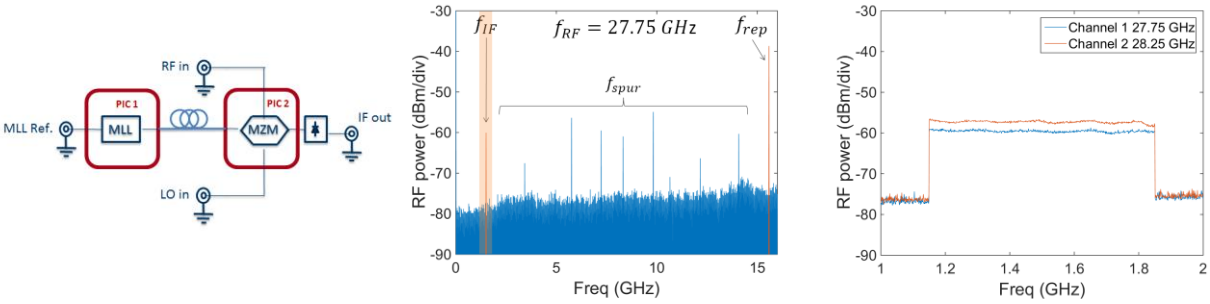

Figure 1: From left to right: Schematic of the electro-photonic frequency down-converter, 0 to 16 GHz spectrum generated for channel 1 (27.75 GHz center frequency) with IF band highlighted, sweep over 700 MHz around the IF for channel 1 and 2.

Both the MLL and the MZM are realized on an IIIV-on-Si photonic integration platform [2]. Two different multi-quantum well layer stacks are heterogeneously integrated on a silicon-on-insulator photonic circuit. The MLL has a threshold current of 60 mA when the saturable absorber is biased at -2.7 V. The waveguide coupled output power is 2 dBm. The demonstrated MZM has a Vpi of 2 V and an insertion loss of approximately 6 dB. With a length of only 1.5 mm, it is more compact and lightweight than a $LiNbO_3$ modulator. While both photonic devices can be integrated on the same chip in a localized architecture, being the ultimate solution that offers high conversion efficiency, the results below are based on a centralized mode-locked laser that is fiber-connected to a III-V/Si Mach-Zehnder modulator. Such an approach allows for the distribution of the optical pulse train to different frequency converters in a communication satellite. For characterization, both MLL and MZM were placed on temperature-controlled stages. The MLL output was collected by an optical fiber through a silicon vertical grating coupler. After being amplified by an EDFA, the pulse train was coupled into the MZM through another vertical grating coupler. One arm of the MZM was driven with a signal generator at 27.75 GHz and the other arm was driven with a LO frequency of 4.918 GHz. The RF is successfully down converted to 1.5 GHz IF frequency. The overall resulting RF spectrum created by beating the modulated pulses on a 30 GHz photodiode is shown in Fig. 1. While many different beat notes can be seen, the frequencies of the MLL and LO were chosen in such a way that no spurious peaks occur in a 700 MHz band around 1.5 GHz. A flat response over 700 MHz of the RF channel can be seen in Fig. 1. The experiment was repeated for all channels, and the 700 MHz sweep for the 28.25 GHz channel is also presented in Fig. 1. During the conference detailed characterization of the MLL and MZM will presented together with detailed results from this and further down conversion experiments.

[1] Jinxin Liao et al, "High-efficiency microwave photonic harmonic down-conversion with tunable and reconfigurable filtering," Opt. Lett. 39, 6565-6568 (2014)
[2] G. Roelkens et al, "III-V-on-silicon photonic devices for optical communication and sensing", Photonics (**invited**), 2(3), p.969-1004 (2015)